Container Port Production Efficiency: A Comparative Study of DEA and FDH Approaches

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Abstract: Container terminal production is both an important and complicated element in the contemporary global economy. Amongst other methods, the efficiency of container port or terminal production can potentially be analysed by Data Envelopment Analysis (DEA) or by the Free Disposal Hull (FDH) Model. This paper aims to evaluate the efficiency of the world's most important container ports and terminals using the two alternative techniques. The results show that the available mathematical programming methodologies lead to different conclusions. It is also concluded that the availability of panel data, rather than cross-sectional data would greatly improve the validity of the efficiency estimates derived from all the mathematical programming techniques applied.

Key words: Data Envelopment Analysis (DEA), Free Disposal Hull (FDH), Container Terminals, Ports, Efficiency, Production.

1. INTRODUCTION

The globalisation of the world economy has led to an increasingly important role for transportation. In particular, container transportation plays a key role in the process, largely because of the numerous technical and economic advantages it possesses over traditional methods of transportation. Standing at the crucial interface of sea and inland transportation, the significance of the container port and its production capabilities cannot be ignored.

Compared with traditional port operations, containerisation has greatly improved port production performance because of two reasons. To reap economies of scale and of scope, liner shipping companies and container ports are respectively willing to deploy dedicated container ships and efficient container handling systems. In so doing, port productivity has been greatly enhanced. On the other hand, many container ports no longer enjoy the freedom yielded by a monopoly over the handling of cargoes from within their hinterland. They are not only concerned with whether they can physically handle cargo but also whether they can compete for cargo. This inter-port competition, under the orthodox microeconomic framework, is believed to provide an incentive to improve port performance. Productive efficiency, therefore, is a survival condition in a competitive environment.

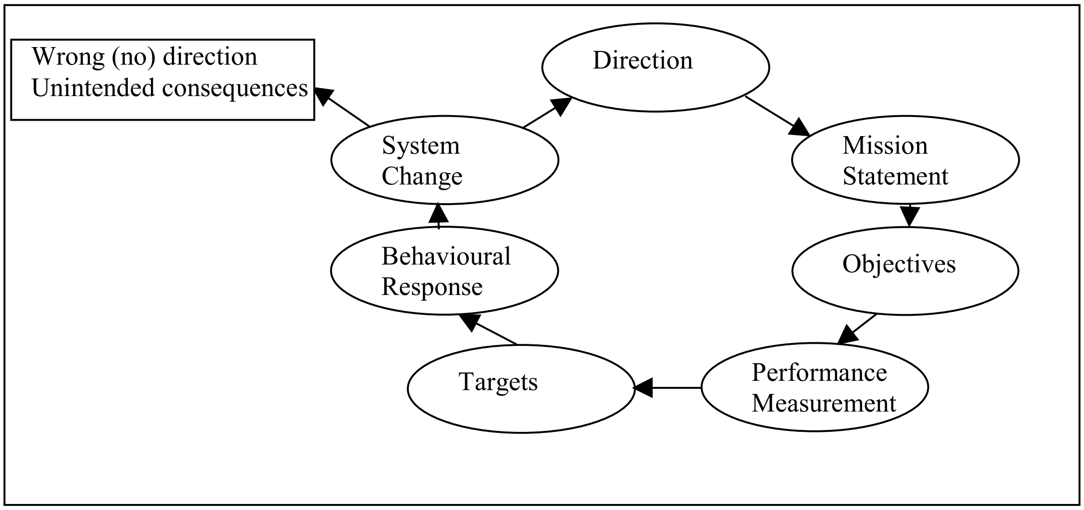
Under such a competitive environment, port performance measurement is not only a powerful management tool for port operators, but also constitutes a most important input for informing regional and national port planning and operations. Traditionally, the performance of ports has been variously evaluated by calculating cargo-handling productivity at berth (Bendall and Stent, 1987; Tabernacle, 1995; Ashar, 1997) by measuring a single factor productivity (De Monie, 1987) or by comparing actual with optimum throughput over a specific time period (Talley, 1998). In recent years, significant progress has been made in the measurement of efficiency in relation to productive activities. In particular, non-parametric frontier methods such as Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) have been developed with applications across a wide range of sectors including transit services. A recent work by De Borger, Kerstens and Costa (2002) claims that frontier models (including DEA and FDH) have found their way into the transport sector, and studies on the productivity and efficiency of almost all transport modes are appearing. Marlow and Paixão (2002) advocate that DEA should be used for port performance measurement and its suitability has been examined by Wang, Cullinane and Song (2003). As the counterpart of DEA, however, it is surprising that FDH has seldom been applied to the transportation industry, and never to the container terminal industry specifically.

Against this background, this paper aims to provide new information on efficiency estimation by applying the two alternative techniques of DEA and FDH to the same terminal data set derived from the world's leading container ports. The paper is structured as follows: section 2 investigates performance measurement in relation to port production. A brief overview of non-parametric efficiency measurement techniques, discussing the relationship between different DEA models and the FDH model, is included in section 3. Operationalisation and the analysis of results are provided in sections 4 and 5 respectively. Finally, conclusions are drawn in section 6.

2. PORT PRODUCTION MEASUREMENT

Performance measurement plays an important role in the development of a company or any other form of organisational Decision Making Unit (DMU)[1]. Dyson (2000) claims that performance measurement plays an essential role in evaluating production because it can define not only the current state of the system but also its future, as shown in Figure 1. Performance measurement helps move the system in the desired direction through the effect exerted by the behavioural responses towards these performance measures that exist within the system. Mis-specified performance measures, however, will cause unintended consequences with the system moving in the wrong direction.

[1] The term 'DMU' is frequently used in the management science literature, and corresponds to the 'firm' in the economic arena.



Source: Dyson (2000, p. 5)

Figure 1: Performance Measures and Organisational Development

Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport. As such, it is possible that a port may provide sound service to vessel operators on the one hand and unsatisfactory service to cargo or inland transport operators on the other. Therefore, port performance cannot normally be assessed on the basis of a single value or measure. The multiple indicators of port performance can be found in the example of the Australian port industry (Talley, 1994). The indicators are selected from the perspective of the stevedore, the shipping line and the port authority (or port management). Evaluations are made by comparing indicator values for a given port over time as well as across ports for a given time period.

The port performance indicators suggested by UNCTAD (1976), as shown in Table 1, underlie productivity and effectiveness measures and can be used as a reference point.

Table 1: Summary of performance indicators suggested by UNCTAD

Financial indicators	Operational indicators
Tonnage worked	Arrival late
Berth occupancy revenue per ton of cargo	Waiting time
Cargo handling revenue per ton of cargo	Service time
Labour expenditure	Turn-around time
Capital equipment expenditure per ton of cargo	Tonnage per ship
Contribution per ton of cargo	Fraction of time berthed ships worked
Total contribution	Number of gangs employed per ship per shift
	Tons per ship-hour in port
	Tons per ship hour at berth
	Tons per gang hours
	Fraction of time gangs idle

Source: UNCTAD (1976, pp.7-8)

Table 2: The Application of DEA to Ports

References	Objectives of Applying DEA	Data Description	The DEA Model (s)*	Inputs	Outputs
Roll and Hayuth (1993)	To theoretically rate the efficiency of ports	Hypothetical numerical example of 20 ports	CCR	Manpower Capital Cargo uniformity	Cargo throughput Level of service Users' satisfaction Ship calls
Martinez-Budria et al (1999)	To examine the relative efficiency of ports and efficiency evolution of an individual port	26 Spanish ports using 5 observations for each port during 1993-97	BCC	Labour expenditures Depreciation charges Other expenditures	Total cargo moved through the docks Revenue obtained from the rent of port facilities
Tongzon (2001)	To specify and empirically test the various factors which influence the performance and efficiency of a port	4 Australian and 12 other international container ports for the year 1996	CCR Additive	Number of cranes Number of container berths Number of tugs Terminal area Delay time Labour	Cargo throughput Ship working rate
Valentine and Gray (2001)	By comparing the port efficiency, to determine whether there is a particular type of ownership and organisational structure that leads to a more efficient port	31 container ports out of the world's top 100 container ports for the year 1998	CCR	Total length of berth Container berth length	Number of containers Total tons throughput

Talley (1994) goes further by attempting to build a single performance indicator – the shadow price of variable port throughput per profit dollar - to evaluate the performance of a port. This overcomes the drawback of multiple indicators, i.e. that examining whether port performance has improved or deteriorated becomes difficult when changes in some indicators improve performance and changes in others affect it negatively.

In an effort to more properly evaluate port performance, several methods have been suggested, such as the estimation of a port cost function (De Neufville and Tsunokawa, 1981) the estimation of the total factor productivity of a port (Kim and Sachish, 1986) and the establishment of a port performance and efficiency model using multiple regression analysis (Tongzon, 1995).

In recent years, DEA has occasionally been used to analyse port production. Compared with traditional approaches, DEA has the advantage that consideration can be given to multiple inputs and outputs. This accords with the characteristics of port production, so that there exists, therefore, the capability of providing an overall evaluation of port performance. Previous applications of DEA to the port industry are summarised in Table 2. Among the four applications listed, that of Roll and Hayuth (1993) should be treated as a theoretical exploration of applying DEA to the port sector, rather than as a genuine application. This is because no genuine data were collected and analysed.

3.METHODOLOGIES: DEA vs. FDH

An efficient production frontier defines the relationship between inputs and outputs by depicting graphically the maximum output obtainable from the given inputs consumed. In so doing, it reflects the current status of technology available to an industry. Ignoring all the economic complexities associated with the particular or possible source, or cause, of inefficiency (such as technical (productive), allocative or scale efficiency), at its most fundamental level, a DMU is considered efficient if it operates on the efficient frontier. On the other hand, a DMU is regarded as basically inefficient (for whatever reason) if it operates beneath the efficient production frontier.

Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) are two of the many available alternative techniques (categorised either as econometric or as mathematical programming) for estimating an approximation to the efficient frontier. These two mathematical programming techniques allow the measurement of the relative distance that an individual DMU (data observation) lies away from this estimated frontier and, thereby, also yield measures (usually in index form) of the relative inefficiency of the individual DMU in question, as compared to what amounts to an industry 'best practice' output/input ratio.

In fact, DEA and FDH are the two most important non-parametric techniques to measure the efficiency of DMUs with multiple outputs and inputs. First introduced in Charnes, Cooper and Rhodes (1978), DEA has been widely used because it can be applied in a diverse variety of situations and has also been the subject of a number of theoretical extensions that have increased its flexibility, ease of use and applicability (Allen *et al*, 1997). As the counterpart of DEA, FDH first appeared in Deprins, Simar and Tulkens (1984) and according to Lovell and Vanden Eeckaut (1993) is gradually becoming more popular.

Despite the wide application of DEA relative to FDH, some scholars argue that FDH prevails over DEA in terms of 'data fit' (Tulkens, 1993, Vanden Eeckaut, Tulkens and Jamar, 1993). It is fair to say that both DEA and FDH have their respective strengths and weaknesses (Lovell and Vanden Eeckaut, 1993). As such, a comparative study of these two approaches may provide greater insight into the intricacies of measuring production efficiency. Efforts in this respect include, *inter alia*, the efficiency of municipalities (Vanden Eeckaut *et al*, 1993) and the efficiency of retail banking, courts and urban transit (Tulkens, 1993).

DEA and FDH, as two deterministic non-parametric methods, assume no particular functional form for the boundary and ignore measurement error. Instead, the best practice technology is the boundary of a reconstructed production possibility set based upon directly enveloping the observations. These extremal methods use mathematical programming techniques to envelop the data (in a piecewise linear way) as tightly as possible, subject to certain production assumptions that are maintained within the mathematical programming context. FDH assumes strong input and output disposability, with the former referring to the fact that any given level of output(s) remains feasible if any of the inputs is increased, whereas the latter means that with given inputs it is always possible to reduce output(s).

DEA adds convexity to the assumptions maintained by FDH. Convex non-parametric frontiers in the context of DEA allow for linear combinations of observed production units. According to this definition, all linear combinations of observations A and C are feasible in Figure 2.

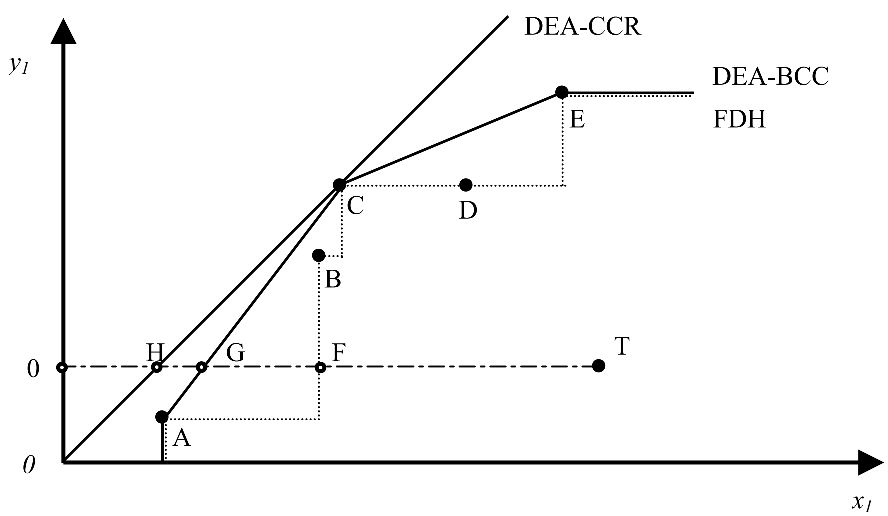


Figure 2: Non-parametric Deterministic Frontiers

Under such circumstances, the FDH efficient unit B is not efficient any more because it is dominated by the new boundary. Figure 2 illustrates the two most widely used DEA-models: The DEA-CCR (due to Charnes, Cooper and Rhodes, 1978) assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. This constant returns to scale DEA frontier is derived simply by the ray through the origin passing through point C. The DEA-BCC model (due to Banker, Charnes and Cooper, 1984) on the other hand, allows for variable returns to scale and is graphically represented by the piecewise linear convex frontier.

FDH, DEA-CCR and DEA-BCC models define different production possibility sets and efficiency results. As an example, the input-oriented efficiency of unit T in Figure 2 is given by 0F/0T as determined by FDH, 0H/0T as yielded by the DEA-CCR model and 0G/0T by the DEA-BCC model.

Formally, let there be s = 1, 2, …, S production units, using inputs $x_s' = (x_{s1}, x_{s2} \cdots x_{sm}) \in R_+^m$ (hereafter, the superscript [′] refers to the transpose of the matrix) to produce outputs $y_s' = (y_{s1}, y_{s2} \cdots y_{sn}) \in R_+^n$. The column vectors x_s and y_s form the s-th columns of the data Matrices X and Y, respectively. Let $\lambda' = (\lambda_1, \lambda_2 \cdots \lambda_S) \in R_+^S$ be a non-negative vector, which forms the linear combinations of the S producers. Finally, let e' = (1, 1, …, 1) be a suitably dimensioned vector of unity values.

An input–oriented efficiency measurement problem can be written as a series of J linear programming envelopment problems, with the constraints differentiating between the DEA-CCR, DEA-BCC and FDH models, as shown in Equations (1) through (6).

$$\min_{\theta,\lambda} \quad \theta \qquad (1)$$

$$s.t. \quad \theta x_s - X\lambda \geq 0 \qquad (2)$$

$$Y\lambda \geq y_s \qquad (3)$$

$$\lambda \geq 0 \quad \text{(DEA-CCR)} \qquad (4)$$

$$e\lambda = 1 \quad \text{(DEA-BCC)} \qquad (5)$$

$$\lambda_s \in \{0,\ 1\} \quad \text{(FDH)} \qquad (6)$$

The combination of Equations from (1) through (4), (1) through (5) and (1) through (6) form the DEA-CCR, DEA-BCC and FDH models, respectively. Interested readers may refer to Seiford and Thrall (1990), Ali and Seiford (1993) and Cooper, Seiford and Tone (2000) for more discussion of the above models.

4. OPERATIONALISTION

4.1. Definition of Variables

A thorough discussion of variable definition is provided in Cullinane, Song and Wang (2003), and can be summarised as follows. The input and output variables should reflect actual container port production as accurately as possible. To this end, a systematic investigation of container production is necessary. As far as container port production inputs are concerned, a container terminal depends crucially on the efficient use of labour, land and equipment. The total quay length, the terminal area, the number of gantry cranes, the number of yard gantry cranes and the number of straddle carriers are the most suitable to be incorporated into the models as the input variables. In the light of the unavailability or unreliability of direct data, information on labour inputs is derived from a pre-determined relationship to terminal facilities. On the other hand, container throughput is unquestionably the most important and widely accepted indicator of port or terminal output. Almost all the previous studies treat it as an output variable, because it closely relates to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Another consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a port. A summary of the major characteristics of the input and output variables is presented in Table 3.

Table 3: Descriptive Statistics for Input and Output Variables

	Throughput (TEU)	Quay length (m)	Terminal Area (ha)	Quayside Gantry (number)	Yard Gantry (number)	Straddle Carrier (number)
Max.	15,944,793	15,718	1,000	99	337	171
Min.	204,496	305	6	3	0	0
Mean	2,293,516	3,208	139	21.6	32	27
Standard Deviation	2,602,174	3,097	170	20	55	40

4.2. Model Choices: Input or Output Oriented

The DEA models can be distinguished according to whether they are input- or output- oriented. Marlow and Paixão (2002) argue that leanness and agility are the two key issues for the survival of a port. Leanness requires the port to eliminate all waste including time, while agility attaches great importance to the volatile marketplace and requires the port to be proactive to the changing market. Leanness is a prerequisite for agility.

The distinction between leanness and agility provides a useful guide for the model choice in terms of the input- or output-oriented question. It is clear that leanness is more closely related to operational matters and as a management strategy is, therefore, easier to implement than agility. A port is normally able to approximately predict its container throughput for the ensuing year at least. This is because a container port has a fairly stable customer base of shipping lines. Over the fairly short-term, container terminals should even be able to predict impending dramatic changes, such as Maersk-Sealand's decision to move its regional hub from Singapore to the Port of Tanjung Pelepas in Malaysia. A container terminal can also attempt to predict its future throughput by studying historic data or regional economic developments. All this suggests that an input-oriented model is most appropriate to the analysis of container production given the output.

4.3. Data Sources

The sampling frame for the analysis was the world's leading container ports ranked in the top 30 in 2001. Out of these 30, the Port of Tanjung Pelepas in Malaysia and San Juan were excluded; the former because it did not officially open until 2000, and the latter because the required data are simply not available. Thus, the sample for analysis comprised a total of 57 observations, of either container ports or individual terminals within container ports. The required secondary data are mainly taken from various issues of both the *Containerisation International Yearbook* and *Lloyd's Ports of the World*. The latest data available on port/terminal throughput was for 1999 and this was chosen as the basis for the analysis.

Based on the argument that container terminals are more suitable for one-to-one comparison than whole container ports (Wang, Song and Cullinane, 2002), this study initially intended to investigate individual container terminals. However, the data source often reported the required data, especially container throughput, at the aggregate level of the whole port, rather than on the basis of the individual terminals that may comprise each of those ports within the sample. In these cases, the input and output of a port are defined as the aggregation of the input and output of individual terminals within the port.

5. RESULTS OF THE EFFICIENCY ANALYSIS AND INTERPRETATION

The software DEA-Solver-PRO 3.0 (Cooper et al, 2000) is employed to solve both the DEA and FDH models. Without precise information on the returns to scale of the port production function, two types of DEA models, namely CCR and BCC model, are applied to analyse the efficiency of container terminals.

Table 4 shows that average efficiency estimates calculated by DEA-CCR, DEA-BCC and FDH respectively demonstrate an upward trend, with average values of 0.5759, 0.7629 and 0.8949 (where an index value of 1.0000 equates to perfect (or maximum) efficiency). Nine out of fifty-seven terminals are identified to be efficient when the DEA-CCR input-oriented model is applied, compared with twenty-three and thirty-seven efficient terminals when the DEA-BCC input-oriented and FDH models are respectively applied. This result is not surprising. As discussed in section 3 and especially in the conceptual illustration shown in Figure 2, a DEA model with constant returns to scale provides efficiency information on pure technical and scale efficiency taken together, while a DEA model with variable returns to scale identifies purely technical efficiency alone. An ANOVA of the efficiency for DEA-CCR, DEA-BCC and FDH analyses ($F = 25.41$) indicates the efficiency measures calculated using these three different approaches are significantly different at the 1% level. Spearman's rank order correlation coefficients between the efficiency derived by DEA-CCR and DEA-BCC, DEA-CCR and FDH, and DEA-BCC and FDH methods are 0.6209, 0.6266 and 0.7558 respectively. The positive and high Spearman's rank order correlation coefficients indicate that the rank of each DMU derived by the three approaches is similar. A combination of ANOVA and Spearman's rank order correlation coefficient leads to the conclusion that the efficiency yielded by the three approaches follows the same pattern across the DMUs.

Table 4: Terminal Efficiency of CCR, BCC and FDH Models (1.0000 = 'efficient')

Port	Port/Terminal	DEA-CCR-I	DEA-BCC-I	FDH
Hong Kong	Hong Kong	0.6922	1.0000	1.0000
	HIT	0.8267	1.0000	1.0000
	MTL	0.4942	0.6407	1.0000
	Terminal 3	1.0000	1.0000	1.0000
	Cosco-HIT	0.6200	0.6414	1.0000
Singapore	Singapore	0.8999	1.0000	1.0000
Busan	Busan	0.2861	0.4732	0.5067
	Jasungdae	0.2505	0.2507	0.2581
	Shinsundae	0.3045	0.3177	0.5455
	Uam	0.3111	0.8333	0.8333
	Gamman_G	0.2686	1.0000	1.0000
	Gamman_Hanjin	0.4187	1.0000	1.0000
	Gamman_Hyundai	0.4477	1.0000	1.0000
	Gamman_K	0.3339	1.0000	1.0000
Taiwan	Kaohsiung	0.9959	1.0000	1.0000
Shanghai	Shanghai	0.7541	1.0000	1.0000
Rotterdam	Rotterdam	0.4601	0.5627	0.6452
	Home	0.7394	0.8842	1.0000
Los Angeles	Los Angels	1.0000	1.0000	1.0000
Shenzhen	Shenzhen	0.4513	0.5862	1.0000
	Yantian	0.6469	0.6940	0.8333
	Shekoui	0.4239	0.7660	0.8250
	Chiwan	0.2987	0.8889	0.8889
Hamburg	Hamburg	0.4774	0.5991	1.0000
	Burchardkai	0.7146	0.7356	1.0000
	Eurokai	0.6662	0.7099	1.0000
	TCT Tollerort	0.4789	0.9107	1.0000
	Unikai	0.1907	0.9091	0.9091
Long Beach	Long Beach	1.0000	1.0000	1.0000
Antwerp	Antwerp	0.3310	1.0000	1.0000
	Europe Terminal	0.6424	0.7066	1.0000
	Seaport	0.1545	0.3484	0.8000
	Noord Natie	0.5481	0.9230	1.0000
	Noordzee	1.0000	1.0000	1.0000
Port Klang	Port Klang	0.2867	0.3681	0.7833
	Klang Container	1.0000	1.0000	1.0000
	Klang Port	0.2097	0.2773	0.2773
Dubai	Dubai	0.4447	0.5176	1.0000
New York/New Jersey	New York/New Jersey	0.6841	1.0000	1.0000
Bremen/Bremerhaven	Bremen/Bremerhaven	0.6094	0.6118	0.6296
Felixstowe	Felixstowe	0.3776	0.4823	0.8226
Manila	Manila	0.3748	0.4202	0.7805
	South Habour	0.4027	0.8889	0.8889
	Manila International	0.2536	0.3200	0.3200
Tokyo	Tokyo	0.5119	0.6187	1.0000
Qingdao	Qingdao	0.4999	0.5678	0.9915
Gioia Tauro	Gioia Tauro	1.0000	1.0000	1.0000
Yokohama	Yokohama	0.3541	0.3549	1.0000
Laem Chabang	Laem Chabang	1.0000	1.0000	1.0000
Tanjunk Priok	Tanjunk Priok	0.5493	0.7292	1.0000
Algeciras	Algeciras	0.9022	1.0000	1.0000
Kobe	Kobe	0.2749	0.3417	0.5517
Nagoya	Nagoya	0.6037	0.6084	0.9179
	Kinjo Pier	0.4332	1.0000	1.0000
	NCB	0.9267	1.0000	1.0000
Keelung	Keelung	1.0000	1.0000	1.0000
Colombo	Colombo	1.0000	1.0000	1.0000
	AVERAGE	**0.5759**	**0.7629**	**0.8949**

Table 4 also shows that the efficiency of different container terminals within the same port and the efficiency of the port as a whole (in aggregate) can either be quite similar (as in the case of Busan and Manila) or quite different (as in the case of Rotterdam and Antwerp). The former might be explained by the fact that different terminals within the same port might learn from best practice of their intra-port competitors, especially when they have similar operating conditions. The latter might be accounted for by the different situations of terminals within the same port. For instance, some terminals in the port might serve solely the major international shipping lines, in which case state-of-the-art equipment might be used and a high efficiency can be achieved. However, a feeder terminal might have lower efficiency because of the use of relatively old equipment, even though the amount of equipment may be the same as that in the terminal serving the international lines.

The relationship between efficiency and production size (as measured by the container throughput at ports) is analysed using Spearman's rank order correlation coefficient. The respective results are 0.3460, -0.1078 and 0.0401 for DEA-CCR, DEA-BCC and FDH analyses. The small absolute value of the Spearman's rank order correlation coefficients suggests that the efficiency of a port is not significantly influenced by its size. This is in contrast with the assumptions that large container ports may take advantage of economies of scale and are thus more efficient than the their smaller counterparts.

Table 5: Summary Results on Numbers of Efficiency Terminals with DEA Models and FDH model

		CCR-I		BCC-I		FDH	
Category of Container throughput (TEU) (1)	Terminals in this Category (2)	Efficient terminals (3)	% [=(3)/(2)] (4)	Efficient terminals (5)	% [=(5)/(2)] (6)	Efficient terminals (7)	% [=(7)/(2)] (8)
0-99,999	19	2	11%	8	42%	11	58%
100,000-199,999	14	4	29%	5	36%	9	64%
200,000-299,999	13	1	8%	2	15%	8	62%
300,000-399,999	3	1	33%	2	67%	3	100%
400,000-499,999	3	1	33%	2	67%	2	67%
500,000+	5	0	0%	4	80%	4	80%
Total	**57**	**9**	**16%**	**23**	**40%**	**36**	**60%**

It is interesting to explore why some large container ports are not associated with higher efficiency values, as one might expect. Table 5 summarises the results presented in Table 4. It shows the efficient terminals at different intervals in terms of scale of production as measured by container throughput, and provides some insights into the rationale of the two different DEA models and FDH. As far as FDH is concerned, ‘Efficiency by dominating’ and ‘efficiency by default’ are the two sources of efficiency *per se* (Vanden Eeckaut *et al*, 1993). The former can be illustrated by the first category (throughput of 0-99,999 TEUs) in Table 5. Eleven out of nineteen terminals are efficient in the context of FDH because they are not ‘dominated’ by any other terminals. However, within the same size category, some of them dominate other inefficient ports. For instance, Terminal 3 of Hong Kong container port dominates all of South Harbour (Manila) Shekou (Shenzhen) Klang Port (Port Klang) and Manila International (Manila). The concept of ‘efficiency by default’ is demonstrated by looking at category 4 (in the throughput range of 300,000-399,999 TEUs). All three terminals (Antwerp, Hamburg and Los Angeles) in this category are FDH efficient. A further investigation of the results reveals that these three ports do not dominate any other ports. They are ‘efficient by default’ simply because they are not dominated by any other ports.

A further comparison between throughput categories 1 through 3 and categories 4 through 6 leads to the conclusion that the larger samples (categories 1 through 3) tend to yield more FDH and DEA-BCC inefficient terminals compared with smaller samples (categories 4 through 6). This is because a DMU in a small sample has less counterparts to be compared against and, therefore, has less chance to be dominated. However, this conclusion is not appropriate for the results from applying the DEA-CCR model (for instance, no single DMU out of five in category 6 is efficient, compared with two out of nineteen, four out of fourteen and one out of thirteen DEA-CCR efficient DMUs in Categories 1, 2 and 3 respectively). Given the assumption of constant returns to scale in the DEA-CCR model, all the DMUs with different production sizes in the different categories can be compared. This can be explained by the production possibility set defined by the DEA-CCR model (Cooper *et al*, 2000).

In practice, an FDH-efficient DMU is not necessarily better than its counterparts with lower efficiency, although an FDH-efficient DMU may lose the incentive to improve its production efficiency because they are already efficient in terms of FDH. This is an important drawback of applying the FDH methodology in a management context. DEA, to some extent, can overcome this drawback in that it constructs a hypothetical convex hull to nest the DMUs. In so doing, some FDH-efficient DMUs may become DEA-inefficient. For instance, three FDH-efficient (= 11-8) and nine FDH-efficient terminals (= 11-2) in the first size category in Table 5 (throughput of 0-99,999 TEUs) become inefficient according from applying, respectively, the DEA-BCC and the DEA-CCR models. The DEA methodology (using either form of model) provides a greater opportunity for DMUs to be benchmarked. On the other hand, without strong *a priori* support, the constructed convex hull might be too artificial to be convincing and feasible (Vanden Eeckaut et al, 1993).

Table 6: A Projection of Inefficient DMU to be Efficient

MTL (Hong Kong)	Actual Value	Projection Value		
		DEA-CCR-I	DEA-BCC-I	FDH
Efficiency		**0.4942**	**0.6407**	**1.0000**
Quay length (m)	1,822	900	1,167	1,822
Terminal area (ha)	79.6	39	51	79.2
Quayside Gantry (number)	19	9	10	19
Yard Gantry (number)	70	22	33	73
Straddle Carrier (number)	3	0	2	0
Throughput (TEU)	2,594,000	2,594,000	2,594,000	2,594,000

One of the fundamental functions of both DEA and FDH methodologies is diagnosis. This constitutes a form of inquiry and experimentation, and facilitates learning (Epstein and Henderson, 1989). Take Modern Terminal Limited (MTL) of Hong Kong port as an example for analysis. Table 6 intimates how this terminal could improve the efficiency of its production under the assumptions implicit in the different performance measurement models. Under the assumption of constant returns to scale (DEA-CCR-I) and variable returns to scale (DEA-BCC-I) one scenario might be that the berth length of this terminal should be reduced to 900 m and 1167 m respectively. On the basis of the results from the FDH model, however, this terminal need not do anything to improve itself because it is already efficient. A similar analysis can also be made for terminal area and any other aspect of factor inputs that have been incorporated into the analysis. Difficulties arise, however, in assessing the joint effect of combined changes.

6. CONCLUSIONS

This paper contributes to the extant research in that the two non-parametric approaches of DEA and FDH have, for the first time, been studied comparatively within the container terminal industry. Analysis of the efficiency yielded by two DEA models (CCR and BCC) and the FDH model confirms that the DEA and FDH mathematical programming methodologies tend to give significantly different results. Thus, the choice of methodology matters if one is interested in ranking DMUs in terms of efficiency and seeking to identify the potential source for improvements in the production of inefficient producers.

It is clear that a combination of DEA and FDH analysis can be of great significance and value to the managerial decisions of ports and terminals and to the strategic decisions of port authorities. On the one hand, the results from applying the FDH model identify the most obvious efficient counterpart(s) for the inefficient DMUs to learn from in terms of realistically comparable industry ‘best practice’. This result is convincing because these efficient counterparts are real. However, the FDH model is more likely to identify as efficient, DMUs that are not really performing that well. In this respect, DEA has greater potential to provide efficient goals for the DMUs to work towards, although these goals should be subject to further study in terms of their feasibility in practice.

Cross-sectional data were utilised in this study. One of the surprising results is to find that some renowned container terminals, such as MTL in Hong Kong, are currently suffering from inefficient production. On the basis of using cross-sectional data, however, this inefficiency could very likely be caused by a recent investment in future production. In order to overcome this potential source of bias in the efficiency estimates derived, an approach based upon panel data is more suited to an analysis that attempts to deduce the long-term efficiency trends of container terminals.

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